LSST Systematics Caused By Observing Strategy & Milky Way Dust

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Abstract

Starting in 2022, the Large Synoptic Survey Telescope (LSST) will survey the southern sky with unprecedented detail. To understand the potential sources of artifacts induced in the observed data, we investigate the effects of depth variations resulting from survey strategy, photometric calibration errors, and Milky Way dust. Using the LSST Operations Simulator and the Metric Analysis Framework, we implement observing strategies with large telescope pointing offsets (dithers) and account for dust extinction using the Schlegel-Finkbeiner-Davis dust map. Our results illustrate how the observing strategy, calibration errors, and dust extinction produce fluctuations in the co-added survey depth, with dust dominating the largest angular scales. We find that while large-scale dust modulations make it more difficult to visualize the strong honeycomb pattern of depth variations in an undithered survey, the honeycomb-induced spurious power still remains in the angular power spectrum. Furthermore, while dust extinction creates much larger systematics than photometric calibration errors, survey strategy is the dominant source of artificial fluctuations in galaxy number density on ~ degree scales relevant for Baryon Acoustic Oscillations. These artificial fluctuations correspond to the survey window function, which can be corrected for in correlation function analyses for weak lensing and large-scale structure studies. We note that a limiting systematic will be generated by uncertainties in this window function, making uncertainties in the dust extinction on all relevant scales a crucial systematic for LSST. Our work illustrates an approach to quantitatively analyze the effects of Milky Way dust and LSST observing strategy upon weak lensing studies.

Background & Methods: What does survey uniformity mean for WL & LSS studies?

Various factors affect the uniformity of data. To simulate the survey depth after the 10-year survey, we use HEALPix to tile the sky with equal area pixels. Since the baseline LSST observing strategy tiles the sky with hexagons inscribed in the the circular FOV (shown in Fig. 1), we use HEALPix to tile each hexagon with ~50 pixels. Then using LSST Operations Simulator (OpSim) output, we simulate the survey depth with fixed telescope pointing and with large dithers (i.e. on the scale of the FOV) .

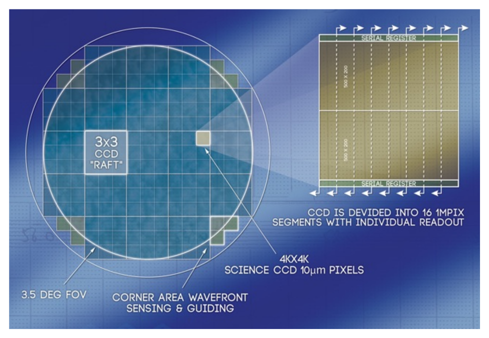


Fig 1: LSST Field-of-View (FOV)
(Image courtesy of Tony Tyson)

We consider dithering strategies with three different time scales (by season, by night, and by visit) to probe the effects of the timescale on which the dithers are implemented. We also consider various geometrical patterns for the dithers (restricted to within the hexagon inscribing the FOV). These include:

- **Random:** offsets are chosen such that every new dither is a new random point.
- **Fermat spiral:** 60 offsets are located on the Fermat spiral: r ~ sqrt(θ); θ ~ the golden angle (137.508°).
- **SequentialHex:** 217 points arranged on a hexagonal lattice are assigned sequentially.

In order to probe the impacts of survey non-uniformity on weak lensing and large-scale structure studies, we consider the fluctuations in the galaxy counts, ΔN/<N>, in each HEALPix pixel arising due to the fluctuations in the co-added depth (using galaxy count power-law relations drawn from mock LSST catalogs), and focus on the effects of the observing strategy, Milky Way Dust, photometric calibration errors, and magnitude cuts on the artificial fluctuations arising from the non-uniformity of the data after the 10-year survey. We account for the dust extinction using the Schlegel-Finkbeiner-Davis dust map when calculating the coadded depth; see Fig. 3 for the *r*-band dust map. Then we model the photometric calibration errors in each HEALPix pixel as being proportional to the deviation from the average seeing over the WFD region, and inversely proportional to the square root of the number of observations in that pixel. For each strategy, we normalize these errors to match the intended 1% calibration uncertainties after the 10-year survey; see Fig. 5 for skymaps of these errors for the undithered survey and a dithered one. Finally, we implement magnitude cuts. Using the power spectra of these ΔN/<N>, we then examine the window function (average across *gri* spectra) and window function uncertainty (variance across *gri*).

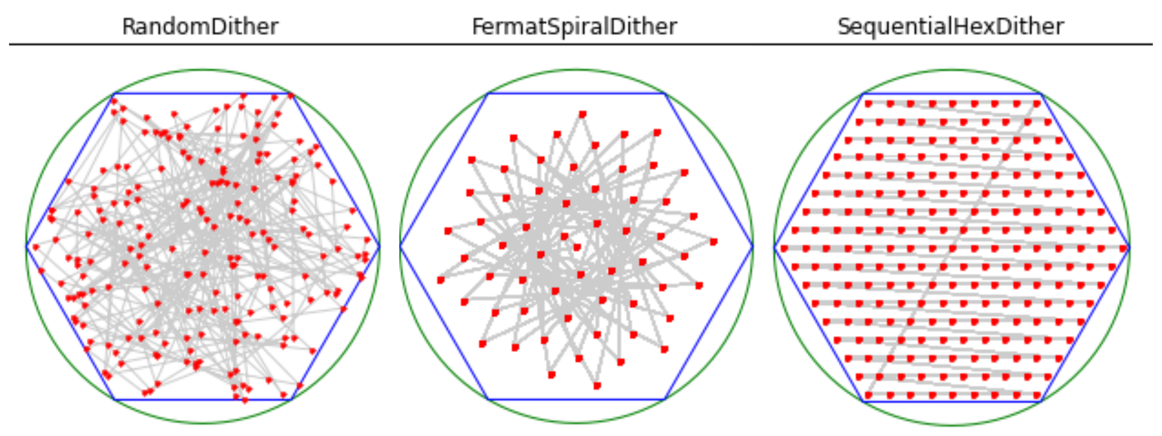


Figure 2: Example Dither Geometries

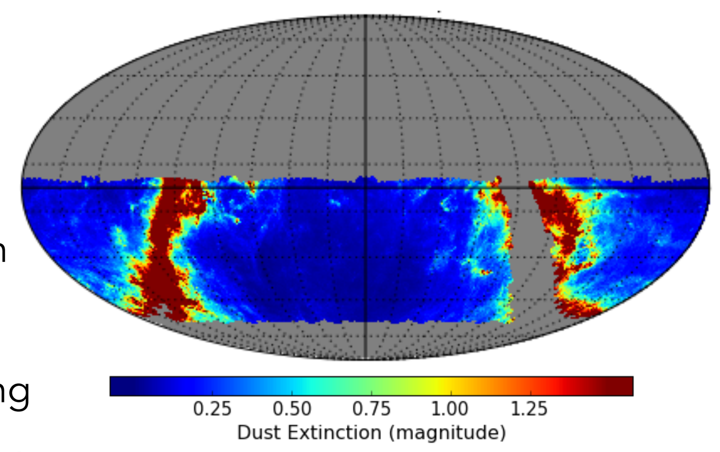
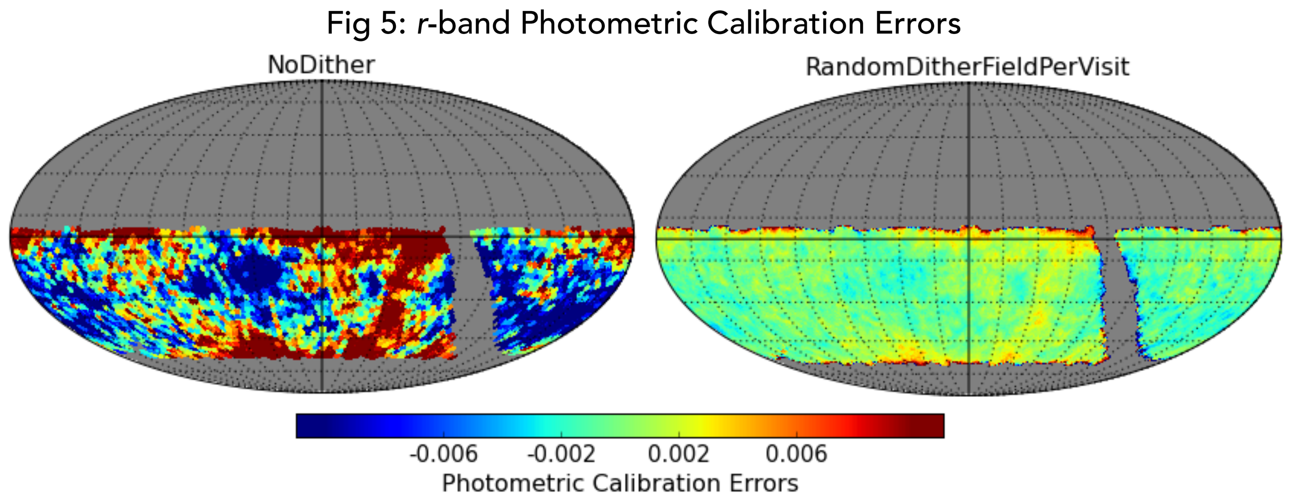


Figure 3: *r*-band Dust Map

Fig 5: *r*-band Photometric Calibration Errors



Results: What's the dominant source of artificial structure? Limiting systematics for WL and LSS studies?

Through our analysis, we find that large dithers significantly increase the survey uniformity and reduce the spurious power induced by the observing strategy (by at least 10x). We find that both by-night and by-visit timescales are effective, with some dither geometries performing better than the others (e.g. SequentialHex geometry induces significant spurious power, especially when the dithers are implemented for every field when it is observed on a new night). Here we show the results from the most effective timescale: by-visit. In Fig 4a, we show skymaps for the *r*-band artificial galaxy fluctuations for the undithered survey and the RandomDither survey without accounting for dust extinction and photometric calibration errors. As can be noted, the undithered survey leads to a strong honeycomb pattern given that the overlapping regions between adjacent FOVs are observed more, while Random dithers reduce such non-uniformity. In Fig 4b, we show the skymaps including dust extinction and photometric calibration errors. We find that Milky Way dust dominates the large-scale structure but not the small-angle structure. Most importantly, it does not wash out the honeycomb pattern in the undithered survey or its low-level residual in the dithered surveys. Also, we find that the photometric calibration errors do not significantly alter or add to the structure (as the errors are small; see Figure 5). In Figure 4c, we show the skymaps for the artificial structure with a magnitude cut (*r*<27.5), where we note that the honeycomb is weaker and the dithered survey is much more uniform (except for the greater depth in the Deep Drilling Fields).

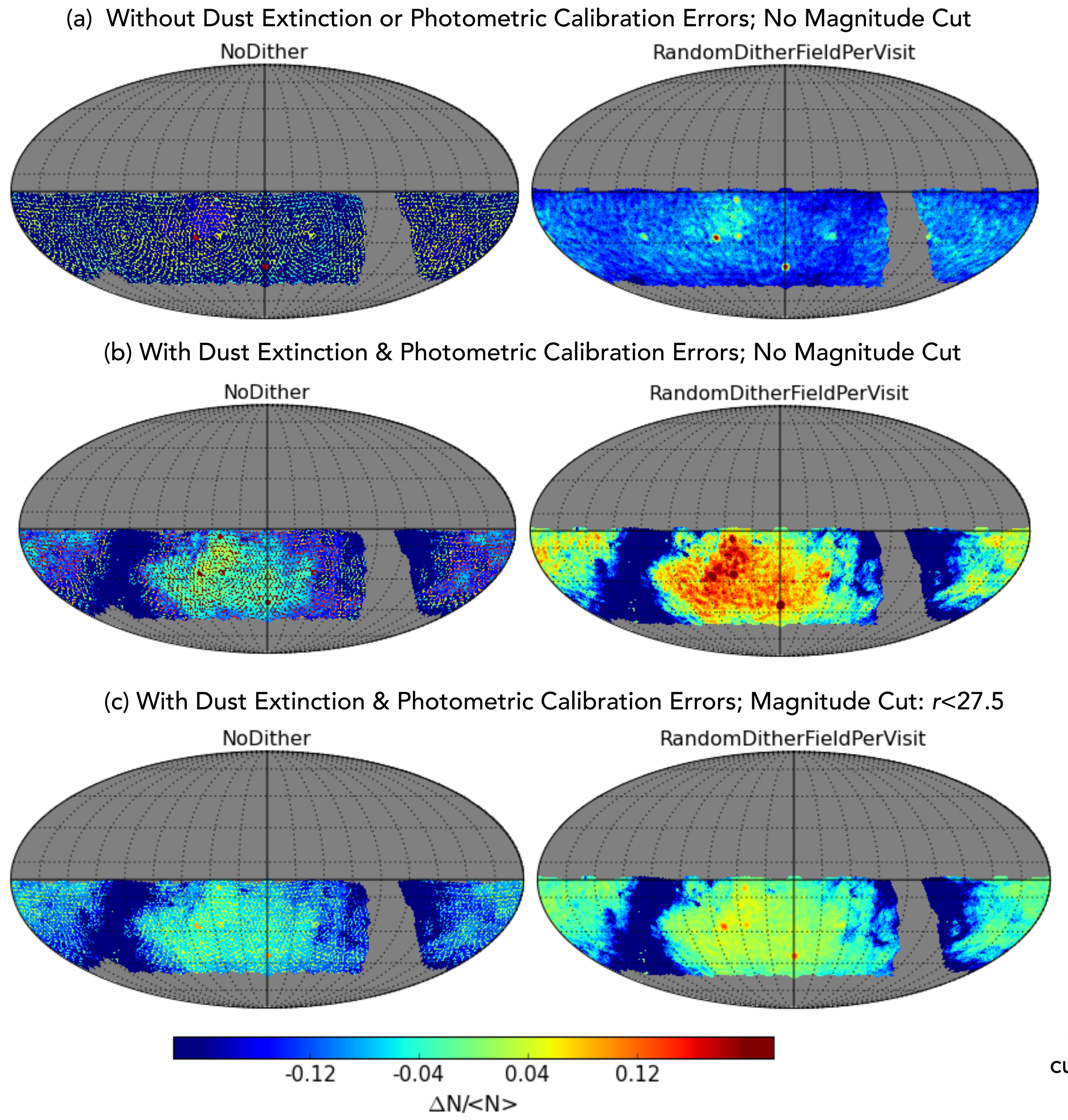


Fig 4: *r*-band Artificial Galaxy Counts Fluctuations

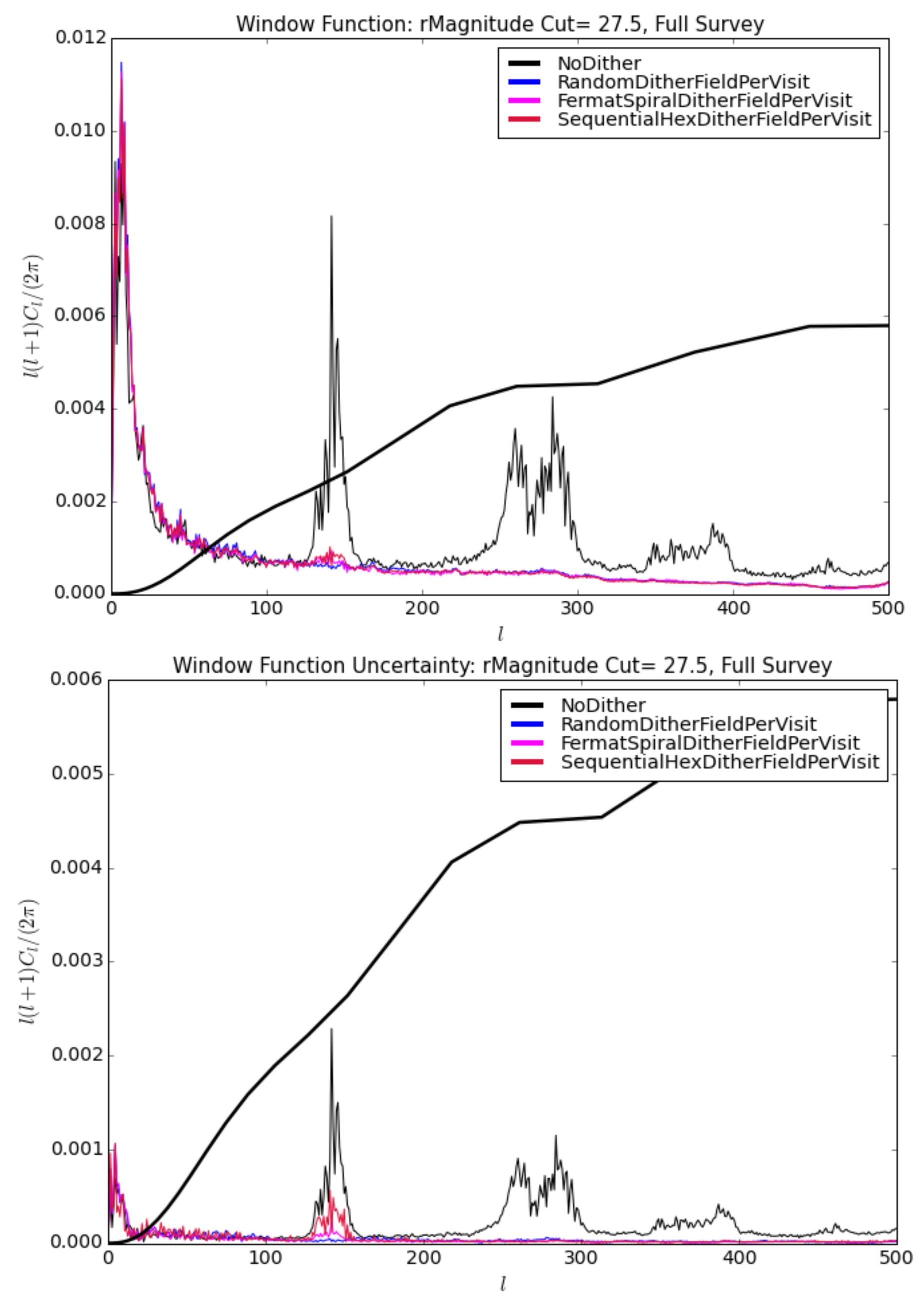


Fig 6: Window Function (top) and Window Function Uncertainty (bottom) for 1.5<z<2.0 with *r*<27.5. Thick black curve is the galaxy power spectrum for 1.5<z<2.0; the wiggles are the BAO signal. **For BAO studies, it is imperative that window function uncertainty is small enough to allow BAO signal measurement.**

In Figure 6, we show the window function and its uncertainty for 1.5<z<2.0 at a magnitude cut of *r*<27.5, including the results from the undithered survey as well as three dither geometries implemented on the by-visit timescale. We also plot the galaxy power spectrum for the same redshift bin, where the curve wiggles represent the BAO signal. The window function uncertainty is therefore a limiting systematic for measuring the BAO signal. We note how SequentialHex geometry leads to window function uncertainty larger than other geometries on the same timescale, highlighting the crucial role observing strategy plays for WL and LSS studies. While dust contributes little at present to the window function uncertainty, we have yet to model the uncertainties in the dust extinction map as a function of wavelength; this could significantly increase the corresponding uncertainties in the window function.

Conclusions: What have we learned? What's next?

Our analysis demonstrates that large telescope-pointing offsets are necessary for a uniform survey, as they increase the survey uniformity and decrease the spurious power, thereby reducing systematic errors. We find that neither Milky Way dust nor photometric calibration errors affect the spurious power as much as the observing strategy and magnitude cuts. For further analysis, we will probe more robust models for window function uncertainty and calibration errors, including those due to Milky Way dust. Also, the observing strategy analysis needs to be expanded to include the effects of rotational dithers on WL studies.

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